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A NEW CALORIMETRY DESIGN FOR ASSESSING PROPOSED TECHNOLOGIES IN LOW ENERGY POWER PRODUCTION

by

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December 2012

Thesis Advisor: Richard Harkins

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As a method to measure heat sources for various mechanical, electrical and chemical processes, calorimeters have been used for many years. This project was conducted to develop, build, test and measure heat production with a Novel Calorimeter designed to detect excess heat for various processes. An energy balance analysis was conducted by restricting the change in input heat and output to near zero. The work term was also held near zero and attempts were made to make the response independent of steam quality. The data and results suggest that the calorimeter was able to run continuously and achieve close to ambient temperatures under adjusted flow rates. Suggestions are proposed to improve the design of the Novel Calorimeter.

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**A NEW CALORIMETRY DESIGN FOR ASSESSING PROPOSED
TECHNOLOGIES IN LOW ENERGY POWER PRODUCTION**

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ABSTRACT

As a method to measure heat sources for various mechanical, electrical and chemical processes, calorimeters have been used for many years. This project was conducted to develop, build, test and measure heat production with a Novel Calorimeter designed to detect excess heat for various processes. An energy balance analysis was conducted by restricting the change in input heat and output to near zero. The work term was also held near zero and attempts were made to make the response independent of steam quality. The data and results suggest that the calorimeter was able to run continuously and achieve close to ambient temperatures under adjusted flow rates. Suggestions are proposed to improve the design of the Novel Calorimeter.

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I. INTRODUCTION

A. MOTIVATION

Energy is possibly the most crucial topic of our generation. Humanity so far has been able to refine air and water and to guarantee food supplies for many generations. On the other hand, energy reserves are not adequate even for current needs ([2], [3]); energy consumption is rapidly increasing globally as the years pass, by due to the industrialization of many developing countries and a worldwide population increase. It is common knowledge that currently available fossil fuels will not last forever; moreover, their environmental effects have been proven to be harmful ([4], [5]).

Many believe that renewable energy sources are the solution to our energy demands; it is possible that in the future this will be the case. However, up to the present time, current technologies are not sufficient to meet demand ([6]). The two major problems that renewable energy faces so far are the cost of current technologies, which is huge, and the inconsistency of its output, as it is dependent on factors that humanity cannot control. On the other hand, nuclear fission, which nowadays used for energy production in reactors is a process that includes the possibility of run-away, which can cause extensive radioactive pollution over a large area, as happened in Chernobyl (April, 1986) and in Fukushima (February, 2011). The promised cheap energy that the Soviet Union and Japan expected from their nuclear reactors has been burdened with the cost of rehabilitating the environment and the accident victims. Furthermore, the management of radioactive waste products is a problem that has not yet been solved; the current solution of storing them in old mines cannot certainly be permanent.

As new methods for alternative energies are researched and explored, there remains a need to accurately measure excess heat production from the processes associated with these new sources.

Calorimeters are used to measure heat during mechanical, electrical or chemical reactions. This thesis explores the feasibility of using a Novel Calorimeter to measure excess heat production for various energy processes.

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B.   THESIS OBJECTIVE

A Novel Calorimeter is designed, built and tested in attempt to verify an energy balance analysis as depicted in Figure 3.

C.   THESIS OUTLINE

There is a short reference on thermodynamics and basic calorimeter analysis that accounts for the experimental implementation. Following there is information and sketch of the proposed novel calorimeter and the first version of which that was built for the purpose of this thesis in order to evaluate the basic concepts of the method. Furthermore there are the extracted data from the experimental execution and some suggestions for the specific device future enhancement. At the end, there are some recommendations and suggestions for future research.

II.   EXPERIMENTAL SETUP AND ANALYSIS

A.   INTRODUCTION

The present chapter presents the design and energy balance analysis of a novel calorimeter. This design is simple, and has features required for the ability to able to operate indefinitely, and to be independent of any characteristics of the heat bearing fluid. Moreover, the calorimeter can easily be tested for accuracy and/or repeatability.

This chapter also reports on a first version of this novel calorimeter. The first experimental results suggest that the design "works" in a broad sense as promised, but that some modifications in the original design are required for sufficient accuracy.

B.   CALORIMETER ANALYSIS

In this section there is a short reference to thermodynamic theory and equations that are used for the proposed calorimeter data analysis.

1.   Conservation of Mass

If we consider "M" to be the mass of the system and assume that the total mass is conserved, then the only process by which mass enters and leaves the system is by a mass flow

$$\left[\begin{array}{c}\text{Amount of M in} \\ \text{the system at t+}\Delta\text{t}\end{array}\right] - \left[\begin{array}{c}\text{Amount of M in} \\ \text{the system at t}\end{array}\right] =$$

$$\left[\begin{array}{c}\text{Amount of M that} \\ \text{entered the system} \\ \text{between t and t+}\Delta\text{t}\end{array}\right] - \left[\begin{array}{c}\text{Amount of M that} \\ \text{left the system} \\ \text{between t and t+}\Delta\text{t}\end{array}\right]$$

Using the term M_k to represent the mass flow rate into the system at the k point, we have ([1]):

$$\frac{dM}{dt} = \sum_{k=1}^{K} M_k \quad \text{(1)}$$

We can also write the same equation in the form of moles by considering N the number of moles in the system and m the molecular weight, so N=M/m and N_k represents the molecular flow rate:

$$\frac{dN}{dt} = \sum_{k=1}^{K} N_k$$

Considering M_1 the total mass of the system at time t_1 and M_2 the total mass at time t_2 and by integrating:

$$\int_{t_1}^{t_2} \frac{dM}{dt} dt = M(t_2) - M(t_1) = M_2 - M_1 \quad \text{(2)}$$

But from (1)

$$\int_{t_1}^{t_2} \frac{dM}{dt} dt = \sum_{k=1}^{K} \int_{t_1}^{t_2} M_k dt = \sum_{k=1}^{K} M_k \int_{t_1}^{t_2} dt = \sum_{k} M_k \Delta t \quad \text{(3)}$$

So from 2, 3:

For steady flow

$$M_2 - M_1 = \sum_{k} M_k \Delta t$$

And in the form of moles

$$N_2 - N_1 = \sum_{k} N_k \Delta t$$

Also for closed systems we can write

$M_2 = M_1$ and $N_2 = N_1$

2. Conservation of Energy

According to thermodynamic theory, when a fluid enters or leaves the system, it carries energy in the form of internal, potential, and kinetic energy. Considering Θ to be the sum of these energies for a "perfect" black-box system we have:

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$$\Theta = U + M\left(\frac{v^2}{2} + \psi\right)$$

Where: U is the total internal energy

$M\frac{v^2}{2}$ is the kinetic energy, if we consider v the velocity of the center mass.

ψ is the potential energy per unit mass. If gravity is the only force presented then ψ=g•h , where g is the gravity force and h the height of the center of the mass.

Following is the law of energy conservation for thermodynamics that could be extracted:

Amount of Θ in the system at t+Δt	−	Amount of Θ in the system at t	=

Amount of Θ that entered the system between t and t+Δt	−	Amount of Θ that left the system between t+Δt	+	Amount of Θ that produced by the system between t+Δt

Since energy is a conserved quantity we can derivate:

$$\frac{d}{dt}\left[U + M\left(\frac{v^2}{2} + \psi\right)\right] = \boxed{\text{Rate of the energy that enters the system}} - \boxed{\text{Rate of the energy that leaves the system}}$$

3.   Energy Balance

In order to calculate the energy balance of the system, it is necessary to identify and determine the mechanisms through which energy enters and leaves the system.

Energy flow accompanying mass flow. A fluid that enters or leaves a system carries an amount of energy with it, in the form of internal, kinetic, and potential energy. This is the product of the mass flow and the energy per unit mass and expressed through the equation:

$$\sum_{k=1}^{K} M_k \left[U + M \left(\frac{v^2}{2} + \psi \right) \right]_k$$

Heat Q. This factor could be either positive, if energy in the form of heat flows into the system, or negative, if heat flows from the system to its surroundings. If heat flows at several points, then the total rate of heat flow is:

$$Q = \sum Q_i$$

Work W. The total energy that flows into the system through work could be divided into several parts.

The work that occurs through the movement of the system boundaries if a force F is applied and a displacement dL is enforced in the time interval of dt, we can call it W_F and it equals:

$$W_F = F \frac{dL}{dt} \quad \text{which equals to } W_F = -P \frac{dV}{dt}$$

Where P is the pressure applied at the system boundaries and dV is the change in volume during the time frame of dt. The minus sign indicates that mechanical energy produced on the surroundings by the system in an expansion (where dV is positive) is negative.

On the other hand, there is also shaft work, which we can express as W_S and includes all other mechanical energy that flows into or out of the system without changing the boundaries of the device. An example is the use of devices such as steering machines, pumps, and others that operate with electric power and the quantity of the shaft work in this case equals:

$$W_{S=} E \cdot I$$

Where E,I are the electrical potential and the current flow in the device.

Work could have either a positive or negative sign if the system absorbs or gives mechanical energy, respectively.

The energy flow that occurs from the fluid's characteristic as a liquid flows does work on the liquid ahead of it and accepts work from the liquid behind it. To evaluate this

we can assume a short tube where a fundamental mass of fluid ΔM_1 enters from one side and at the same time another fundamental mass ΔM_2 exits from the other side.
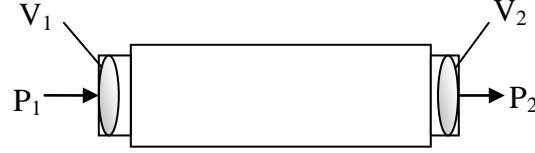
Respectively, the pressure at the entry side is P_1 of a volume V_1 and at the exit P_2 of a volume V_2.

Work done by surrounding fluid in boosting fluid of mass ΔM_1 into the tube entry	$= P_1 \bullet \hat{V}_1 \bullet \Delta M_1$
Work done on surrounding fluid by movement of fluid of mass ΔM_2 out of the tube exit	$= P_2 \bullet \hat{V}_2 \bullet \Delta M_2$
Energy due to the movement of fluid	$= \left(P_1 \bullet \hat{V}_1 \bullet \Delta M_1\right) - \left(P_2 \bullet \hat{V}_2 \bullet \Delta M_2\right)$

In general, for a system with K number of flow ports, the total energy due to pressure forces acting on the liquids that are entering or leaving the system equals:

$$\sum_{k=1}^{K} \Delta M_k (P\hat{V})_k$$

So the net rate for a total mass flow rate M_k equals

$$\sum_{k=1}^{K} M_k (P\hat{V})_k$$

By combining all the terms above, we conclude with the equation of conservation of energy for the system:

$$\frac{d}{dt}\{U + M\left(\frac{v^2}{2} + \psi\right)\} = \sum_{k=1}^{K} M_k \left[\hat{U} + M\left(\frac{v^2}{2} + \psi\right)\right]_k + Q + W_s - P\frac{dV}{dt} + \sum_{k=1}^{K} M_k (P\hat{V})_k$$

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From the equation of enthalpy H of the thermodynamics: H=U+P•V, and by using the letter "W" to represent the shaft work W_S and the work through displacement – P(dV/dt), we can simplify the equation to the following:

$$\frac{d}{dt}\{U + M\left(\frac{v^2}{2} + \psi\right)\} = \sum_{k=1}^{K} M_k \, [\widehat{H} + \frac{v^2}{2} + \psi]_k + Q + W \quad \text{④}$$

This is the general equation of the energy balance.

In the specific case of a steady-system, Equation 4 becomes:

$$steady \ state \ system \rightarrow \frac{dM}{dt} = 0, \frac{dV}{dt} = 0, \frac{d}{dt}\left\{U + M\left(\frac{v^2}{2} + \psi\right)\right\} = 0$$

$$so \ 0 = \sum_{k=1}^{K} M_k \, [\widehat{H} + \frac{v^2}{2} + \psi]_k + Q + W_S \quad \text{⑤}$$

In the event that the system is not moving, this can be further simplified to:

$$0 = \sum_{k=1}^{K} M_k \, \widehat{H} + Q + W_S$$

4.   Steam Quality

In thermodynamic calculations water could exists either in liquid form as fluid water or in vapor form as gas. Generally in boilers there is a distribution of the two forms of water.

The following figure shows a temperature-enthalpy diagram in a closed system with water boiling. The horizontal axis is the enthalpy added, which is actually the energy that we spend to heat the water and the vertical one represents the temperature. At point "A," water is in liquid form and as it warms up (increasing enthalpy/energy), it moves towards point "B." At point "B" for a specific pressure (normally for 1 atm and 100°C) the water will begin boiling. If we continue to increase the heat, the water temperature will not change and we will have a straight horizontal line "χ" (following a constant pressure line) towards to point "C." Along "χ" the water will be in an intermediate state of liquid and vapor form. The quality of the steam is represented by the ratio of the mass of the gas water to the total mass and characterized from 0 at point "B" to 1 at point "C" (0.83 for example for 83% steam and 17% fluid water).

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When we reach point "C" there is no more fluid water but 100% steam this point expressed as "Quality 1.0" or "100% dry" or "0% wet" and after that point the temperature starts increasing again towards to point "D."
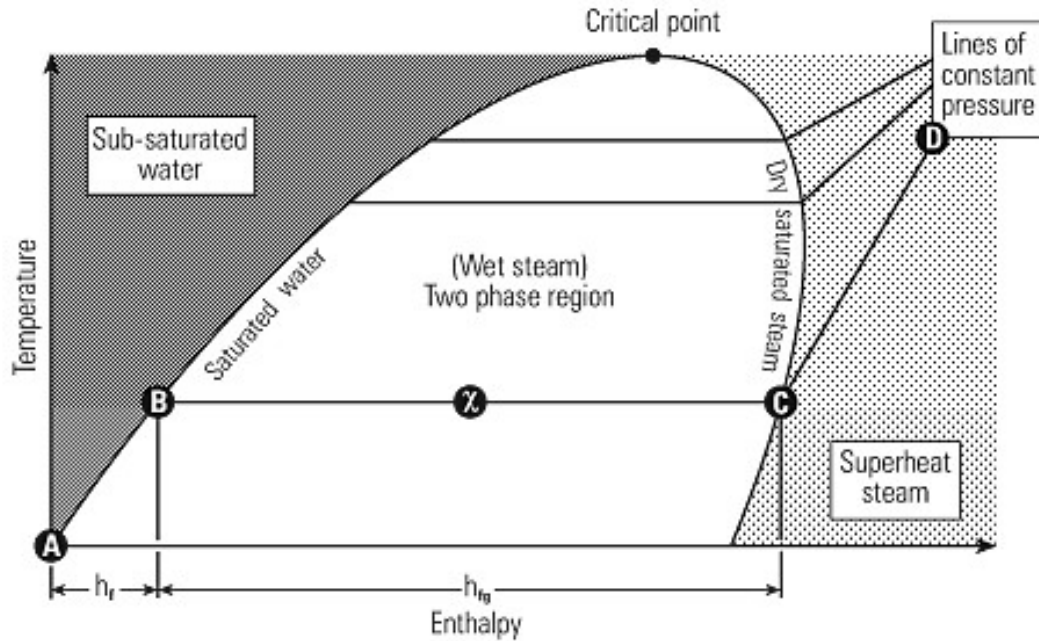

Figure 1.   Temperature enthalpy phase diagram ([7])

If we consider a total mass of water M which consists of liquid water of mass M_{liquid} and vapor mass M_{vapor} the steam quality is M_{vapor} / M.

Generally it is not easy to determine the quality of the steam and many calorimeter methods so far have raised doubts regarding the reliability of their measurements for that reason. Thus, the observation of steam is not enough to obtain safe results from a device's efficiency but the quality of the steam also needs to be calculated.
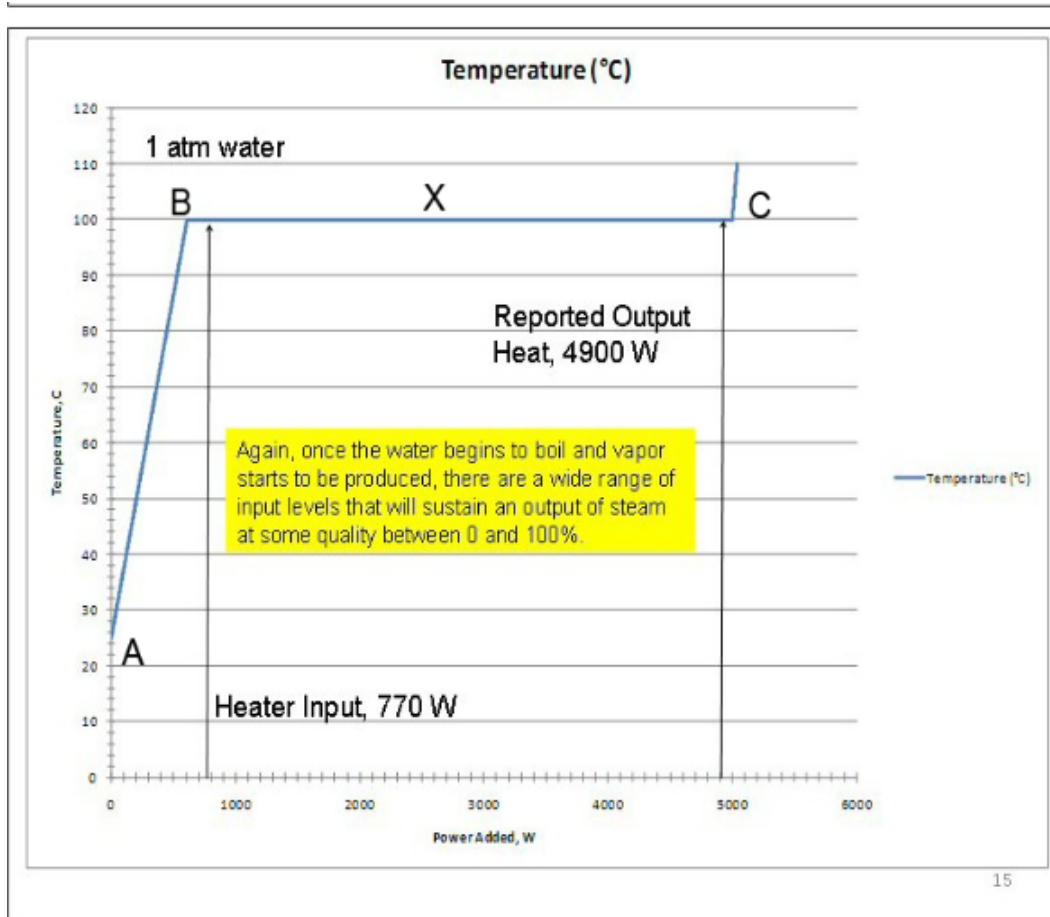
Figure 2.   Temperature of the steam-power added diagram ([8])

C.   BUILDING A CALORIMETER

1.   Experimental Setup

Figure 3 is a sketch of the calorimeter that was developed; it was a configuration for this study. The design of this device could solve problems regarding steam quality and "time-on-steam" treat bring into question some earlier "excess heat" measurements.
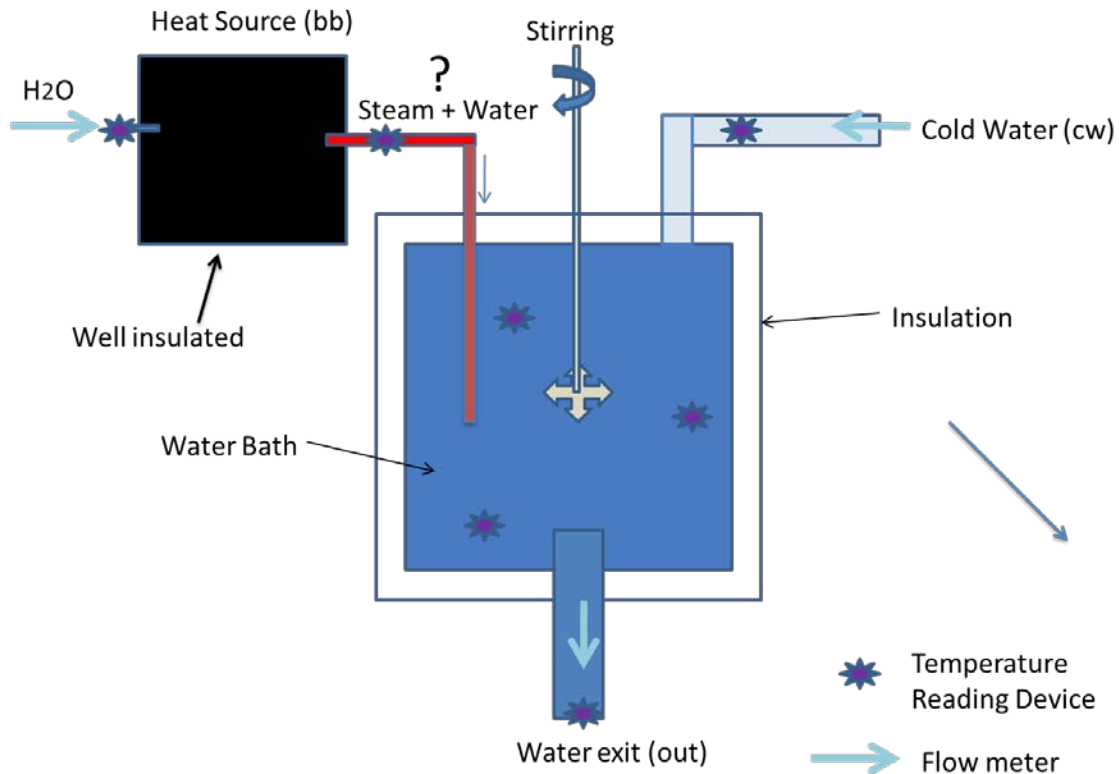
CSTR Water Bath Calorimeter

Figure 3.   Proposed calorimeter sketch

   The system is composed of an insulated steady volume water bath in which two tubes of the ingoing liquids are fitted, one for cold water and the other for hot water or steam. There is a stirring machine that mixes the two liquids and three or more thermocouples inside the bath that measure the temperature of the mixture. An overflow tube is attached with a temperature reading device that counts the temperature of the outgoing fluid. There is another thermometer that has been placed at the cold water input of the system. Finally, there are three flow meters on the three ports of the device (two inputs, one output), calculating the total mass of the ingoing and outgoing liquid.

   The system is designed to: i) simplify the energy balance by reducing ΔQ to approximately zero, ii) make the work term W nearly zero, and iii) make the response independent of steam quality. The operating principle of the device is to keep the value of the outgoing temperature as close as possible to the ambient temperature by adjusting the

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flow and/or the temperature of the cold water source, the fulfillment of which will reduce heat losses to the environment. The first will be achieved by operating the water bath (Figure 34) at ambient temperature. The cold water flow rate will be adjusted in order to achieve this. Indeed, as heat loss is proportional to ΔT ($\Delta T = T_{water\ bath} - T_{ambient}$), reducing ΔT to zero results in no heat transfer from bath to environment. The second is achieved by using a low power stirrer. This can be calibrated. Moreover prior work suggests stirrer input will be of the order of 1 watt. Finally, the third will be achieved by mixing the "hot water" steam of uncertain or unknown quality with cold water to achieve an intermediate ambient temperature of almost 0^0C quality.

This proposed calorimeter is a steady state one with no heat transfer ($\Delta Q=0$), which means that this energy balance stays as follows:

$$0 = dM_{bb}H_{bb} + dM_{cw}H_{cw} - dM_{out}H_{out} + \text{Stir heat}$$

Where M_{bb}, H_{bb} the rate and the enthalpy of the heat source, M_{cw}, H_{cw} the rate and the enthalpy of cold water, M_{out}, H_{out} the rate and the enthalpy of the output.

M_{bb}, M_{cw}, M_{out} is measured from the flowmeters.

H_{cw}, H_{out} is measured from the thermometers.

Stir Heat is a known quantity.

So the enthalpy H_{bb} of the heat source could be calculated

Furthermore, it is important to mention that the "heat input" in the sketch could be replaced with any device that we want to use to measure its output enthalpy. In that case, we should only count the ingoing liquid flow rate of the device. That is, the first term on the right side of the equation $dM_{bb}H_{bb}$ can be treated as a lumped. This will still provide the desired result: a measure of the rate of heat production by the "black box." Consequently this calorimeter could possibly be used in several thermodynamics applications.

As previously mentioned the proposed calorimeter could extract accurate and reliable data on enthalpy measurements and in this way solve the problems that other current methods appear to have.

First, in the proposed calorimeter the fluid runs continuously in order for the system measurements to have integrity over a long period of time, so they are not an instant result of an indefinable factor or something else. This could also overcome concerns regarding "hidden" sources of chemical energy. It is also quite important for real world implementation to have a steady device that can produce results for an energy source that runs continuously. Only this kind of results is useful for comparison to other energy sources.

Second, the device is designed to work to near room temperature, which will reduce the faults in measurements due to losses to its surroundings. Furthermore, the most important feature is that the "problem" with steam quality does not exist and any device can be measured with accuracy and integrity, independently of any characteristics of the heat-bearing fluid.

Last, but not least, the calorimeter can be easily tested for its accuracy and repeatability and could be designed in a relatively compatible form so that it could be easily transferred.

2.   Experimental Implementation

A first version of this proposed calorimeter was built in order to evaluate the basic concepts of the method. Three large plastic cans were used for fulfillment, one with insulation, a heater, a stirring machine, a flow controller/meter, a temperature-controller/meter, a thermocouple, two mercury thermometers, an induction coil, some connectors, switches, insulation materials, and stainless steel and plastic tubing. Water from a common faucet was used as an input to the system. A sketch and an image of the device follow.
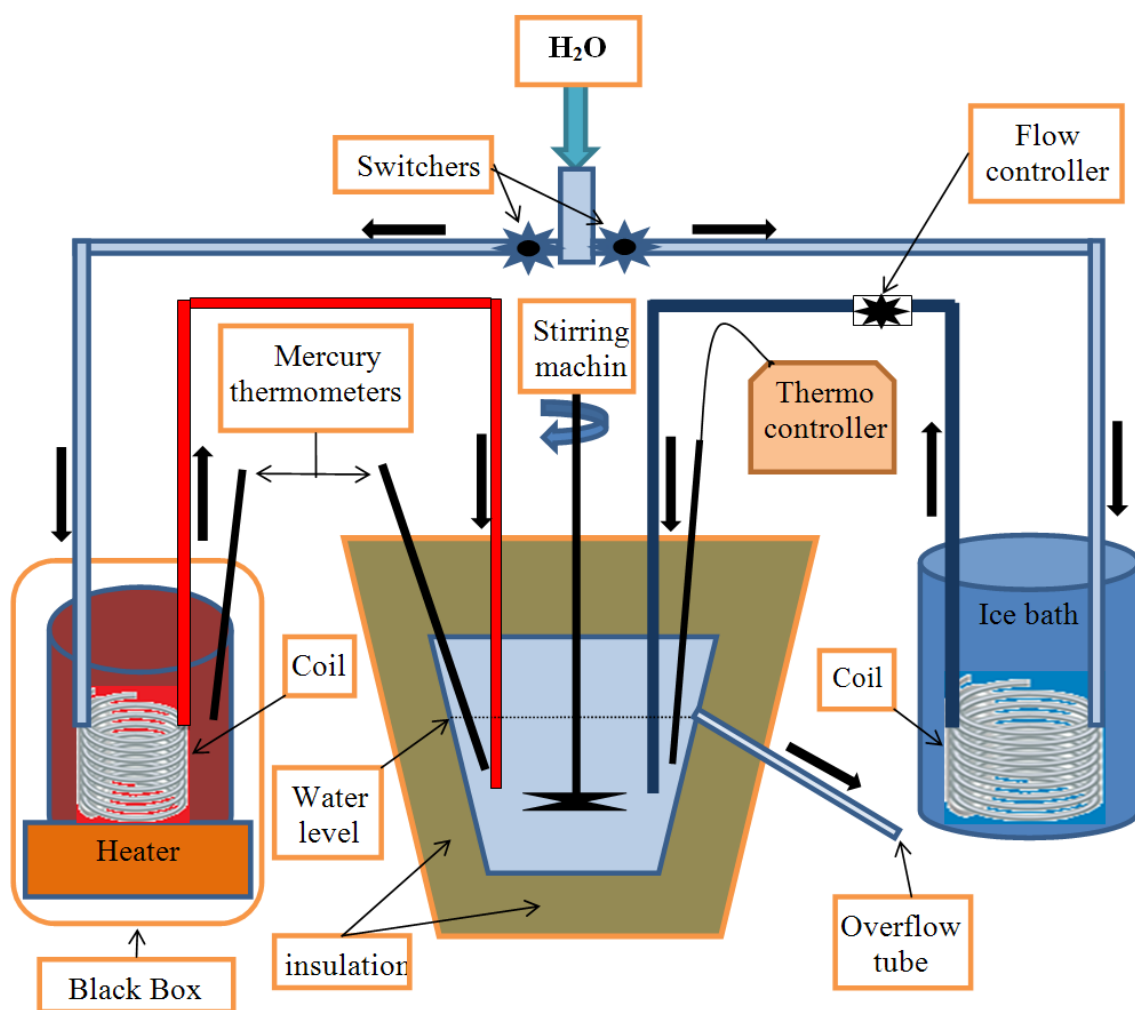
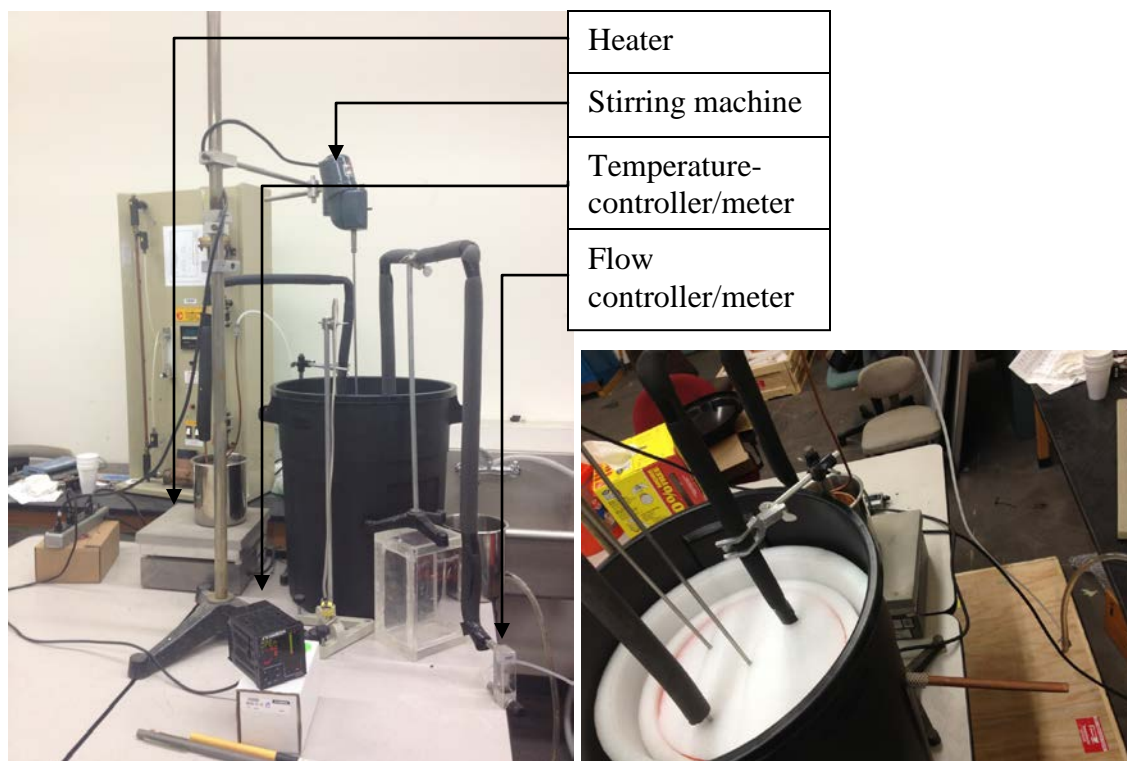Figure 4.   Sketch of the first version of the calorimeter

Figure 5.   First version of the calorimeter

The water exits the faucet and splits via two switches to two tubing structures, which finally both end in the water bath. The first tube is a long plastic one (about ten meters) and goes through an ice bath to the flow controller/meter. Next, there is an insulated stainless steel tube that ends in the water bath. The second tube goes to the induction coil, which is in a pot full of water that is being heated by the heater and follows via an insulated stainless steel tube that also ends in the water bath.

The water bath consisted of two plastic cans, one inside the other with insulation covering the internal one. Inside the bath and approximately at its middle height, both tubes of hot and cold water are flowing. On the lid of the water bath are another three small holes, where the inputs for the stirring machine, the thermocouple, and one of the mercury thermometers are located. There is also an overflow tube at the side through which the outgoing fluid exits the device.

As mentioned, there is a second plastic can full of ice that works as an bath for freezing the ingoing cold water.

Figure 6.　　　First version of the calorimeter

3.　　Experiment Execution – Assumptions – Data

The device was tested thoroughly so as not to have any leaks through the water flow and the tubing connectors. Implementation began with the concession that the mass quantity of the water that enters the system is the same as that exits, assuming that there

are no hidden losses or mass transformations. For that reason, there is no flow meter at the exit; however, it would be a simple and useful addition for a future update.

There is a notable heat loss from the heater to the environment as there is no insulation between the heat plate and the pot. Hence, in this first model the actual heat production rate is not known. A better heat transfer arrangement will be required on the "black box" side for true energy measurement.

Also, the ice bath restricts the operational continuity of the device, as it requires a periodic refill of ice and draining of fluid water due to ice melt.

During the operation of the calorimeter the basic concerns were first to achieve a temperature of the water bath close to ambient temperature and second to check the stability of this temperature balance with or without adjustments to flow rate and/or temperature rate. In this way it was attempted to verify the system's continuous operation, integrity, and reliability.

The first day, after achieving the temperature balance, the flow rate of the ingoing cold water was left steady and checked how the temperature of the water in the water bath changed. The specific results were duplicated more than one time, so their reproducibility must considered a fact. On 11/29/2012 four thermo-insulated bricks were added to the water bath in order to reduce its volume; the measured results were the same without any change. The last day, it was checked how switching to different flow rates could affect or not the temperature of the water bath.

During the measurements the temperature of the ice bath was 0 to 2 ^{0}C.

Room temperature:	25.4^{0}C		Date:	11/25/2012
Time	Flow rate [lt/hr]	Temperature of water bath (thermocouple) [^{0}C]	Temperature of water bath (mercury thermometer) [^{0}C]	Temperature of water in heating pot[^{0}C]
09:00	11.8	25.58	25.6	43

09:10	11.8	25.12	25.1	43
09:20	11.6	25.75	25.8	43
09:30	11.8	24.62	2.5	43
09:40	11.8	25.78	25.6	43
09:50	11	26.53	26.7	43
10:00	11.8	25.44	25.6	43
10:10	11.8	25.5	25.6	43
10:20	11.8	25.2	25.5	43
10:30	11	25.8	25.2	43
10:40	11.4	25.65	25.8	43
10:50	11.8	25.10	25.1	43
11:00	11.8	25.28	25.2	43
11:10	11.8	24.37	24.9	43
11:20	12	23.85	24	43
11:30	11.2	25.41	25.5	43
11:40	11.8	24.62	24.6	43
11:50	11.8	24.87	24.6	43
12:00	11.2	25.44	25.3	43
12:10	11.8	26.12	26	43
12:20	11.8	26.58	26.6	43
12:30	10.8	25.6	25.6	43
12:40	11.8	25.71	25.6	43
12:50	11.4	25.27	25.5	43

13:00	11	26.52	26.5	43
13:10	11.8	24.92	25	43
13:20	11.8	25.64	25.5	43
13:30	12	24.73	24.6	43
13:40	11.4	26.43	26.4	43
13:50	11.4	26.84	26.7	43
14:00	12.4	24.92	25.8	43
14:10	12	24.25	24	43
14:20	12	24.89	24.9	43
14:30	11.4	25.32	25.4	43
14:40	11.0	25.16	25	43
14:50	11.4	25.23	25.2	43
15:00	11.8	24.79	24.9	43
15:10	11.8	25.36	25.2	43
15:20	11.6	25.47	25.4	43
15:30	11.6	25.69	25.8	43
15:40	11.8	25.58	25.6	43
15:50	11.8	25.72	25.7	43
16:00	11.8	25.45	25.5	43

Room temperature:		24.6^{0}C	Date:	11/29/2012
Time	Flow rate [lt/hr]	Temperature of water bath (thermocouple) [^{0}C]	Temperature of water bath (mercury thermometer) [^{0}C]	Temperature of water in heating pot[^{0}C]
09:00	10.8	24.83	24.8	43
09:10	11	24.12	24	43
09:20	11.2	23.98	24	43
09:30	10.8	24.62	24.5	43
09:40	10.8	24.75	24.6	43
09:50	11	24.33	24	43
10:00	11.2	24.26	24.2	43
10:10	10.8	24.95	25	43
10:20	10.8	25.05	25	43
10:30	11	24.89	25	43
10:40	11.2	24.56	24.5	43
10:50	11	24.10	24	43
11:00	11	24.28	24.1	43
11:10	10.8	24.97	25	43
11:20	11	24.76	24.9	43
11:30	11.2	24.11	24.1	43
11:40	11	24.59	24.8	43
11:50	10.8	24.67	24.4	43

12:00	10.6	25.14	25	43
12:10	10.8	24.93	25	43
12:20	11	24.88	25	43
12:30	10.8	24.62	24.6	43
12:40	10.8	24.71	24.6	43
12:50	11	24.63	24.8	43
13:00	11	24.49	24.4	43
13:10	10.8	24.75	24.8	43
13:20	10.8	24.68	24.8	43
13:30	11	24.53	24.4	43
13:40	10.8	24.78	24.4	43
13:50	11	24.84	24.8	43
14:00	10.8	24.87	25	43
14:10	10.8	25.16	25	43
14:20	10.8	24.76	24.8	43
14:30	10.8	24.63	24.6	43
14:40	10.8	24.74	24.8	43
14:50	10.8	24.66	24.6	43
15:00	11	24.35	24.2	43
15:10	11	24.36	24.1	43
15:20	10.8	24.86	24.1	43
15:30	10.8	24.89	24.6	43
15:40	10.8	24.78	24.8	43

Time	Flow rate [lt/hr]	Temperature of water bath (thermocouple) [^{0}C]	Temperature of water bath (mercury thermometer) [^{0}C]	Temperature of water in heating pot[^{0}C]
15:50	10.8	24.83	25.2	43
16:00	10.8	24.93	25	43
Room temperature:		25.8^{0}C	Date:	11/30/2012
10:00	6	27.82	27.8	43
10:30	6	27.65	27.6	43
11:00	6	27.58	27.4	43
11:30	6	27.42	27.4	43
12:00	6	27.38	27.2	43
12:30	6	27.72	27.8	43
13:00	10	26.84	26.6	43
13:30	10	26.55	26.6	43
14:00	10	26.12	26	43
14:30	10	26.37	26.4	43
15:00	10	25.92	26	43
15:30	10	26.24	26.2	43
16:00	22	24.59	24.2	43
16:30	22	24.83	24.8	43
17:00	22	24.59	24.6	43
17:30	22	24.76	24.8	43

18:00	22	24.21	24.1	43
18:30	22	24.43	24.4	43
19:00	30	22.35	22.4	43
19:30	30	22.12	22.1	43
20:00	30	21.98	22	43
20:30	30	22.16	22	43
21:00	30	22.36	22.4	43
21:30	30	22.68	22.5	43

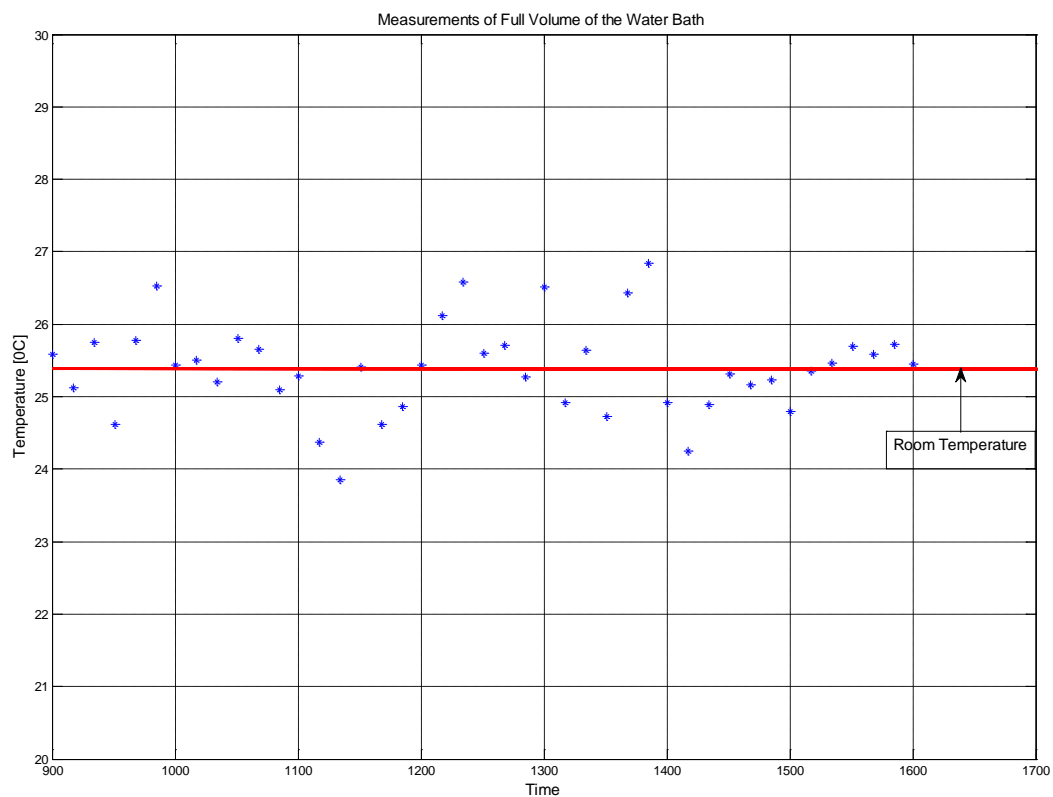Table 1.   First version of the proposed calorimeter data

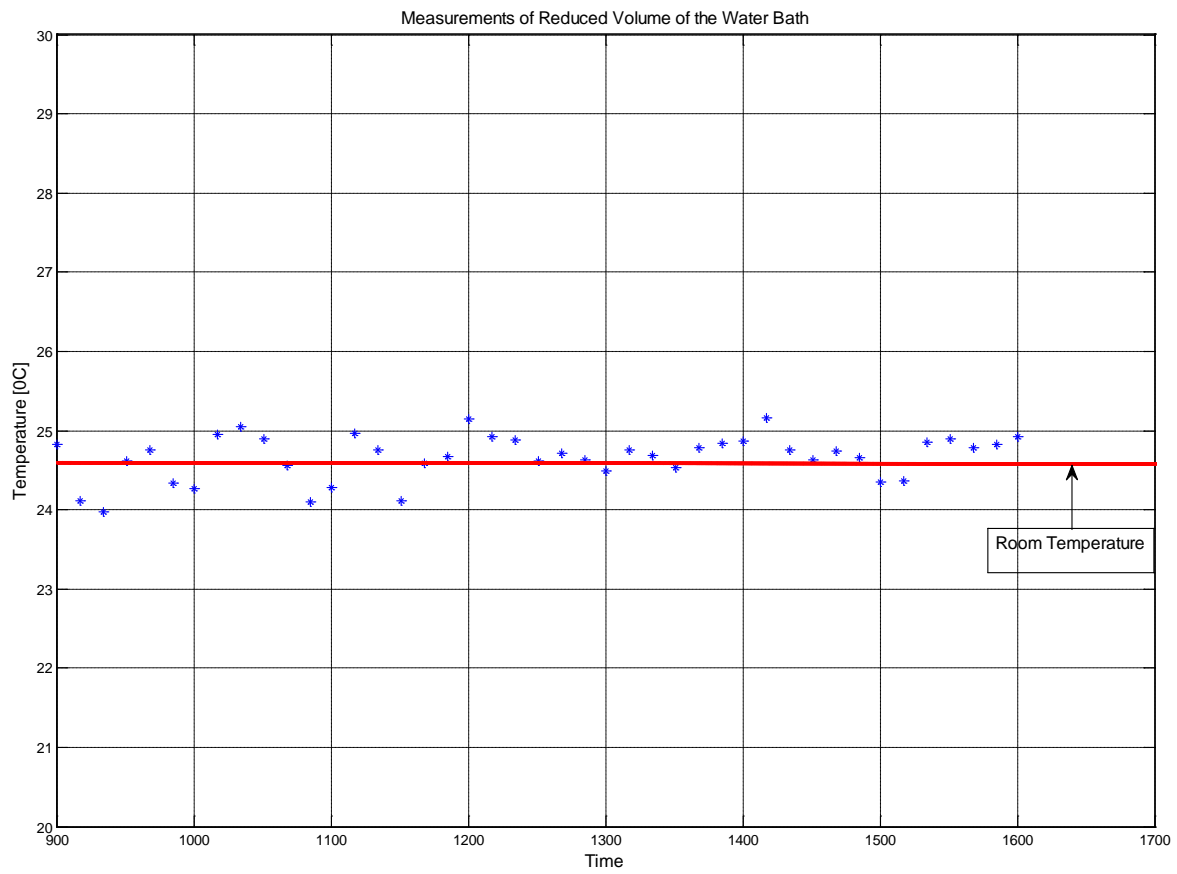Figure 7.   Measurements of full volume of the water bath

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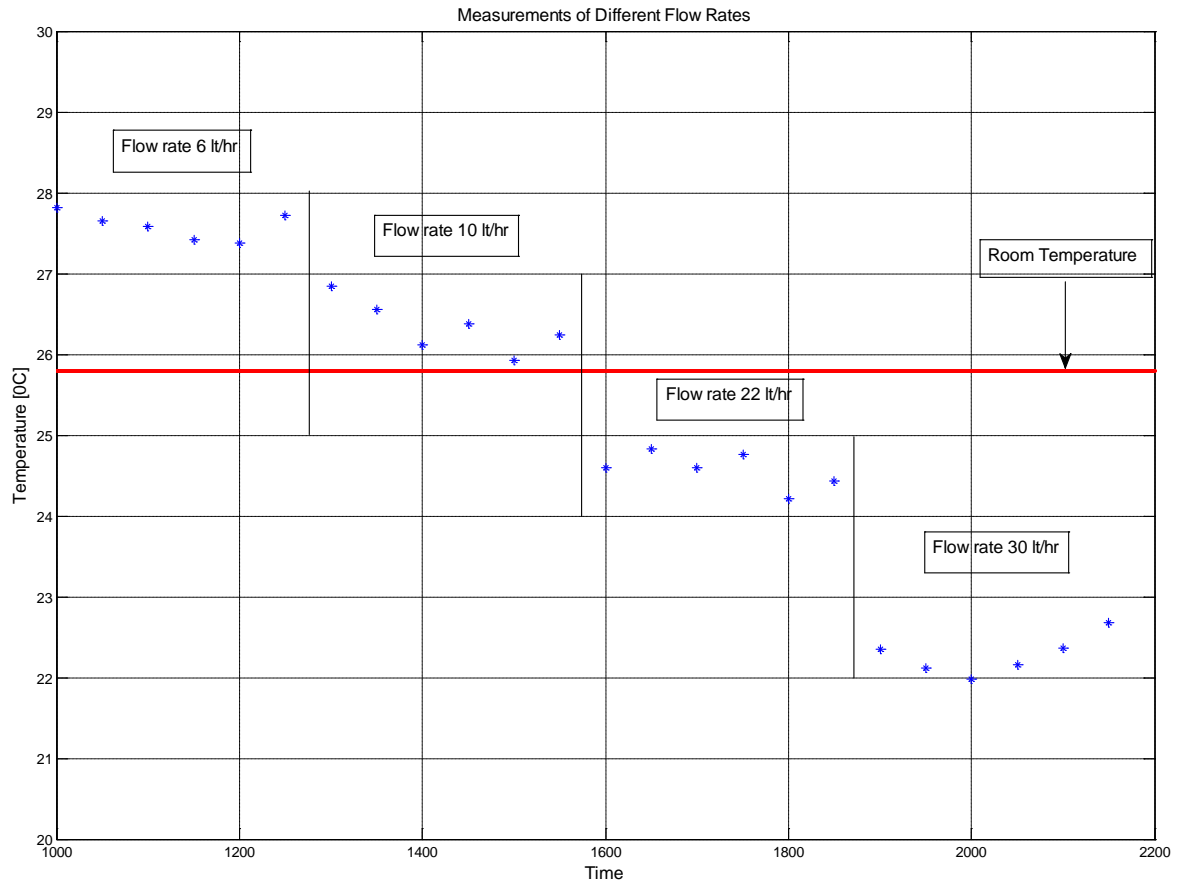Figure 8.   Measurements of reduced volume of the water bath

Figure 9.   Measurements of different flow rates

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III. SUMMARY AND OUTLOOK

A. RESULTS AND CONCLUSIONS

The outcomes of that first implementation are considered positive. First, it is verified that the calorimeter was able to run continuously, with the restriction in our case of refilling the ice bath and the possible consequences that it has on the system's stability. Second, the device was able to easily achieve ambient temperatures, as we can verify from Figures 7 and 8 and considering the adjusted flow rates the specific device with just an ice bath and plastic tubing as freezing process was able to measure high temperature outputs. Furthermore, by adjusting the flow rate we can actually change the temperature of the water bath as we can verify from Figure 9. Thus, the aim of measuring steam temperatures, even with this simple calorimeter, seems executable.

It was also shown that by increasing or reducing the flow rate of the ingoing ice water, it is possible to adjust the temperature of the ice bath.

The accuracy of the device seems to be acceptable but some improvements could increase much more its reliability and integrity as discussed below.

B. SUGGESTIONS FOR DEVICE ENHANCEMENT

First, by checking the measured results of flow rate without any flow adjustments, it appears that the flow output of the faucet is not steady and hence a pump should be employed in order to achieve steady flow.

Second, in order to measure enthalpy with confidence, a thermometer should be used to measure the temperature of the ice water that enters the water bath, and not just the temperature of the ice bath.

Third, a flow meter should be added at the exit of the system in order to verify the ingoing and outgoing water's mass stability.

Fourth, some effort should be made to improve the sensitivity of the water bath to changes in enthalpy coming from the black box. For example, a smaller volume water bath may react more dramatically to changes in input energy.

Finally, heat losses seem not to affect the system's operation, integrity, and accuracy of results due to the fact that the heater plays the role of the device under examination, which in this case is not very efficient.

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